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BATTERY and CELL TESTING
at
Marshall Space Flight Center

Marshall Space Flight Center
Huntsville, Alabama
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ON-GOING BATTERY/CELL TESTING AT MSFC

Hubble Space Telescope Applications:

- Ni-Cd 6, 4-Cell Packs, RSN-55-15
- Ni-H2 14-Cell Pack, RNH-30-1
- Ni-H2 12-Cell Pack, RNH-35-3
- Ni-H2 3, 4-Cell Packs, RNH-90-3
- Ni-H2 Six Battery Test, RNH-90-3
- Ni-H2 "Flight Spare" Battery, RNH-90-3

Other Applications:

- CRRES Ni-Cd Testing
- Ag-Zn 4, 6-Cell Packs, LR 350 DC-1
- Ni-H2 6, 4-Cell Packs, RNH-90-3
- Ni-H2 2, 2-Cell Packs, RNH-90-3

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This presentation is an overview covering the ten cell/battery tests ongoing at Marshall Space Flight Center. The presentation is not intended to give specific results on any test. This presentation acknowledges the purpose and related program that applies to each test.

Except for the Combined Release and Radiation Effects Satellite (CRRES), all are energy-stored and retrieval devices at low earth orbit (LEO) cycles.

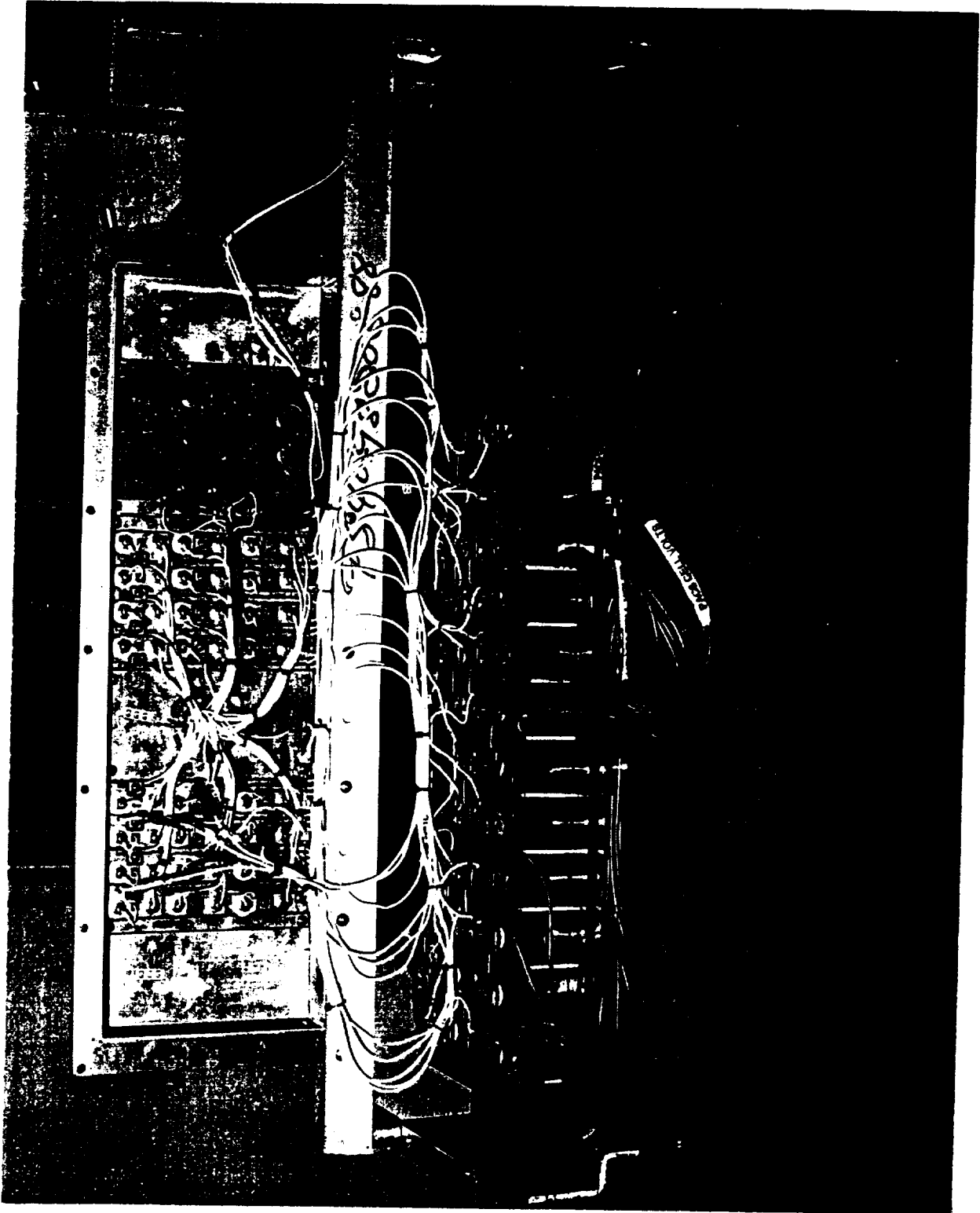
HST NiCd Six, 4-Cell Packs

- 55 ampere-hour cells developed by Eagle-Picher Inc. RSN-55-15, Type 44 Cells
- These were the baseline cells for HST before their replacement by Ni-H₂ batteries.
- Characterize cell behavior and demonstrate life capability of the originally designed HST batteries.
- Completed over 27,000 LEO cycles
- The cells met the 3 year HST capacity requirement even after 59 months of cycling.

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HST Ni-Cd Six, 4-Cell Packs - The 24 Ni-Cd cells are Eagle-Picher, Type 44, RSN-55-15, matched to the six Type 44 flight batteries for the Hubble Space Telescope (HST). These cells were received from Lockheed Missiles and Space Company (LMSC) after ~4 years of LMSC cycling. They represent the baseline cells for HST before their replacement by Ni-H₂ batteries. The packs are configured into six packs of four cells each. The system was designed for the cells to operate at a depth of discharge equivalent to 16 percent of nameplate capacity of 55 ampere-hours during normal cycling. On line since 1990, this test will be used to characterize cell behavior and demonstrate life capability of the originally designed HST batteries.

A modified Battery Protection and Reconditioning Circuit (BPRC) is used to prevent cell reversal during failure and/or reconditioning. This BPRC is one of the six MSFC designed and qualified for flight taken from the Ni-Cd 6-Battery Mission Simulation Test.



HST Ni-Cd Six, 4-Cell Packs

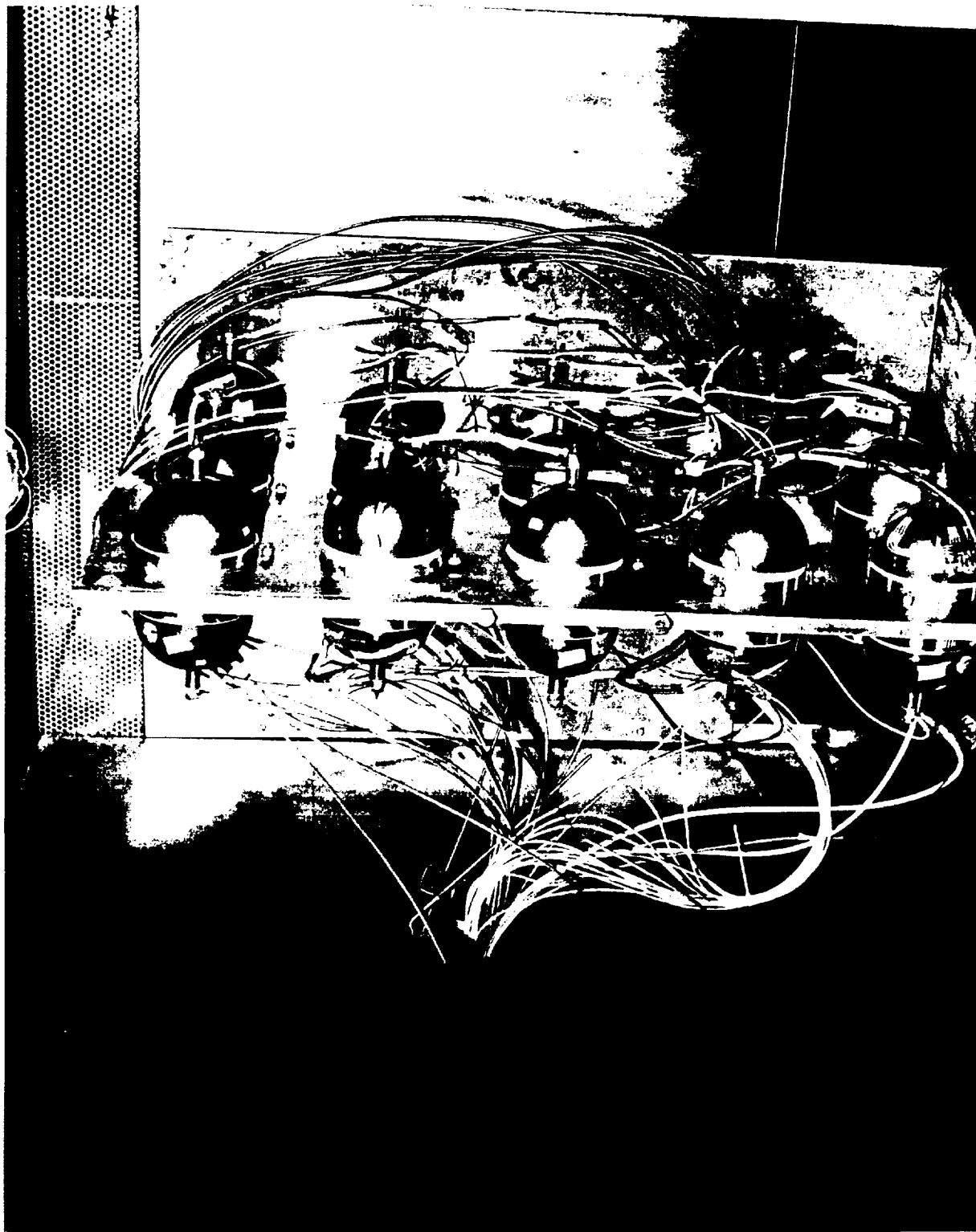
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HST Ni-H₂ 14 Cell Pack

- 30 ampere-hour cells developed by Eagle Picher Inc. RNH-30-1 (COMSAT design)
- On test since 1986, to build data base for Ni-H₂ LEO operation at shallow DODs
- Completed over 26,000 LEO cycles at 13% DOD.
- Capacity after 4.5 years of cycling was 22 Ah.

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HST Ni-H₂ Fourteen Cell Pack - Fourteen Eagle-Picher RNH-30-1 (30 ampere-hour capacity) cells of COMSAT design on test since 1986 (First Ni-H₂ cells to be placed in a low earth orbit (LEO) test at MSFC). These cells were used to gather early data on the LEO operation of Ni-H₂ cells in anticipation of a decision to fly Ni-H₂ cells on the Hubble Space Telescope (HST). The cells have undergone over 26,000 LEO cycles at 13% DOD. The test setup of these cells provides for autonomous operation and parameter management through the use of digital data acquisition and system control, power supply simulation of solar array output with relays to allow reduction of current to trickle charge levels and programmable load banks to simulate varying vehicle load. Cells will continue to cycle in the present setup according to current test parameters to build data base for Ni-H₂ LEO operation at shallow depths of discharge.



HST Ni-H₂ Fourteen Cell Pack

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Ni-H₂ 12 Cell Pack

- 33 ampere-hour (Ah) cells developed by Eagle Picher Inc. RHN-35-3 (Air Force design)
- Activated in 1976, stored, began testing in 1988.
- Completed over 26,000 HST LEO Cycles at 13% DOD with a step-to-trickle charge scheme.
 - Cycling capacity of approx. 27 Ah
- Presently cycling at 22% DOD, with a step-taper charge scheme.

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Ni-H₂ Twelve Cell Pack - Twelve Eagle-Picher RHN-35-3 cells (33 ampere-hour capacity) of Air Force design following a low earth orbit (LEO) (61/35) profile. These cells were activated in 1976 and then placed in storage. MSFC began testing these cells in 1987. These cells are cycling to a depth of discharge (DOD) of 22% based on their 33 ampere-hour nameplate capacity and charging with a taper charge. The test bed for these cells is automated; but very limited due to the age of the components, lack of digital data acquisition, lack of equipment interface ability, etc. Previously these cells were cycling according to an Hubble Space Telescope LEO profile and had accumulated 12,600 cycles at this level. Presently this test has completed over 3,800 cycles with the step taper charge scheme.

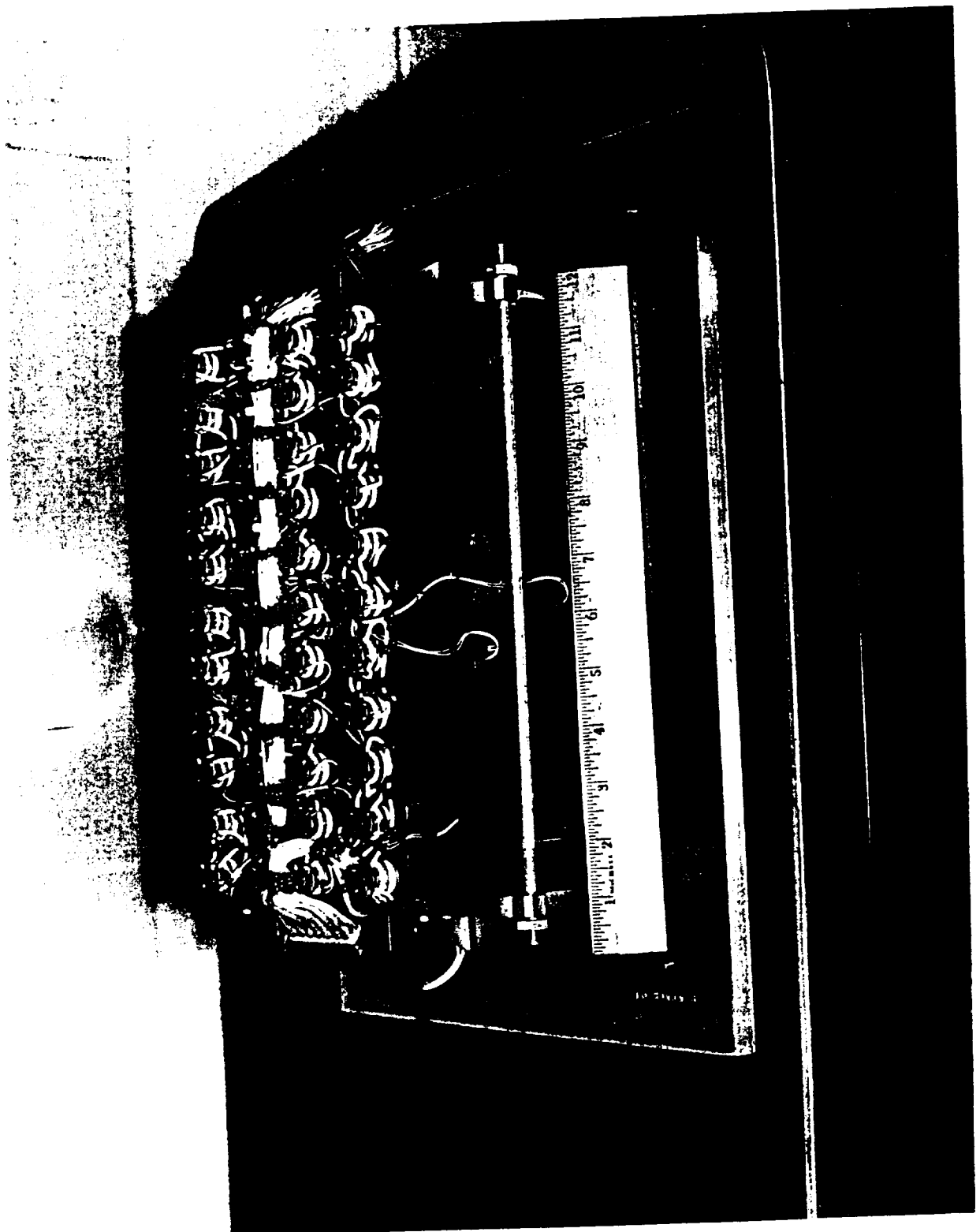
CRRES Ni-Cd Testing

- 18 ampere-hour cells developed by Gates for Ford Aerospace
- Simulating the highly elliptical orbit of the CRRES spacecraft (588 minute orbit)
- Determining the optimum charge levels to maximize battery life and effectiveness
- Completed over 488 orbital cycles ranging from 0 to 50% DOD

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CRRES Ni-Cd Testing - At MSFC testing is being performed on Ni-Cd cells used for the Combined Release and Radiation Effects Satellite (CRRES) program. These Ni-Cd cells were manufactured by Gates for Ford Aerospace and have a nameplate capacity of 18 ampere-hours.

The two MSFC applications which apply to the CRRES program are the Two-Cell Test and CRRES Flight Spare Battery Test (an actual 21 cell battery). They simulate the highly elliptical orbit seen by the CRRES spacecraft. This elliptical orbit has a period of 588 minutes with varying eclipse times. Both tests will undergo an over-temperature, over-charge event experienced on the actual spacecraft. The main objective of these tests is to determine the most efficient charge levels for the actual spacecraft battery to maximize battery life and effectiveness.



CRRES Flight Spare Battery

Silver-Zinc Pack Testing

Four, 6-Cell Packs

- 350 ampere-hour (Ah) cells developed by Yardney.
- Originally tested for OMV; now applicable to CTV
- Determine operational life of similar cells subjected to periodic deep discharges.
- Test profile consist of the following:
 - Shallow DOD LEO cycles (1.2 Ah)
 - Deep DOD "Mission Discharges" (295 Ah)
- 19 Deep Discharges and over 8200 LEO cycles
- Total capacity after 18 months of cycling was 295 Ah.

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Ag-Zn Four, 6-Cell Packs - Testing has been performed on secondary (rechargeable) Ag-Zn cells at MSFC for over 5 years. The latest test involves a Yardney 350 ampere-hour cell design which has cycled over 18 months and has achieved over 8200 low earth orbit (LEO) cycles as well as 19 deep discharges. The four, 6-cell packs (on line since November of 1989) are cycling to determine operational life of similar cells subjected to periodic, deep discharges. In addition, this test addresses different storage methods for these cells between deep discharges. Impedance measurements were made on one of the packs during periodic deep discharges.

This test was originally designed to determine the feasibility of using such a cell in a long-life (18 months) LEO application, which applied to the Orbiting Maneuvering Vehicle (OMV). Results from this test make it a candidate for other programs such as the Cargo Transfer Vehicle (CTV), and the Aeroassist Flight Experiment (AFE).



Two of the Four
Ag-Zn, 6-Cell Packs

HST Ni-H₂ 4-Cell Packs

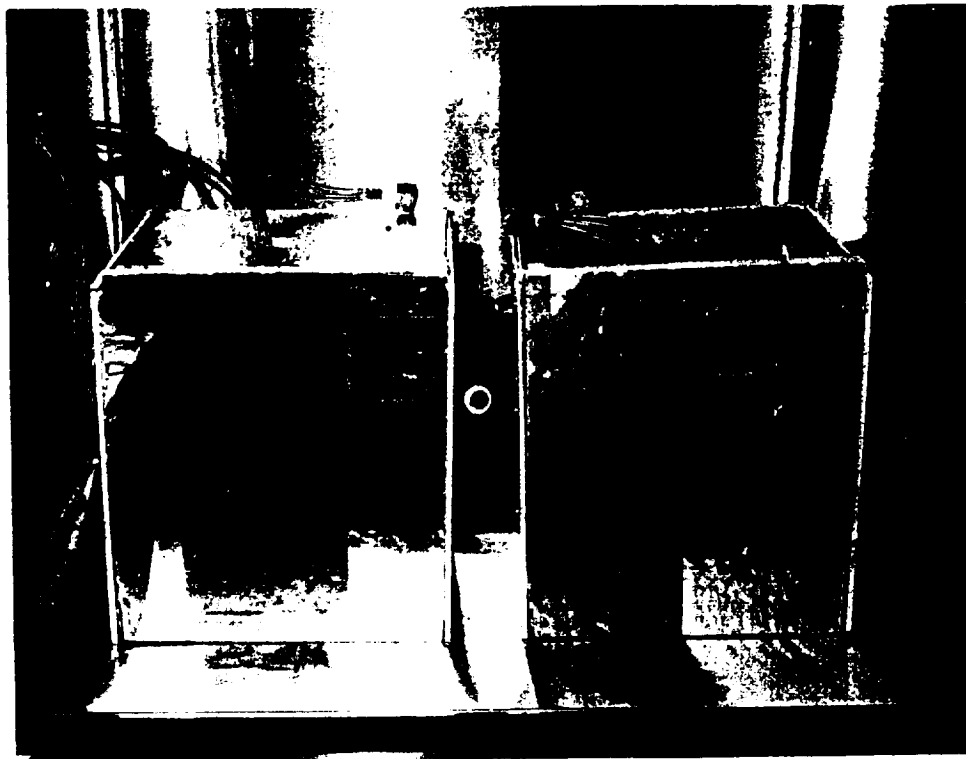
- 88 ampere-hour cells developed by Eagle Picher Inc. for the HST project. RNH-90-3
- One 4-cell pack of TM1 cells, One 4-cell pack of TM2 cells, and One 4-cell pack of FSM cells
- Packs used for parametric testing. First of the HST cells to arrive at MSFC for testing.
- Testing parallels HST system test with ability to investigate proposed changes or duplicate recent occurrences without affecting integrity of system test.
- Months on test TM1- 34 TM2- 32 FSM- 30

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HST Ni-H₂ Three, 4-Cell Packs - Three four cell packs of Eagle-Picher RNH-90-3 cells from different lots (4 Flight Spare Module (FSM) Lot Cells, 4 Test Module 1 (TM1) Lot Cells and 4 Test Module 2 (TM2) Lot Cells) following an Hubble Space Telescope (HST) low earth orbit (LEO) (61/35) cyclic profile at 7% - 9% DOD. The 4 FSM cells were placed in the test bed in March 1989 and are into their 30th month of cycling. The TM1 cells began cycling during November of 1988 and are into their 34th month of cycling while the TM2 cells began cycling in February of 1989 and presently are into their 32nd month of cycling.

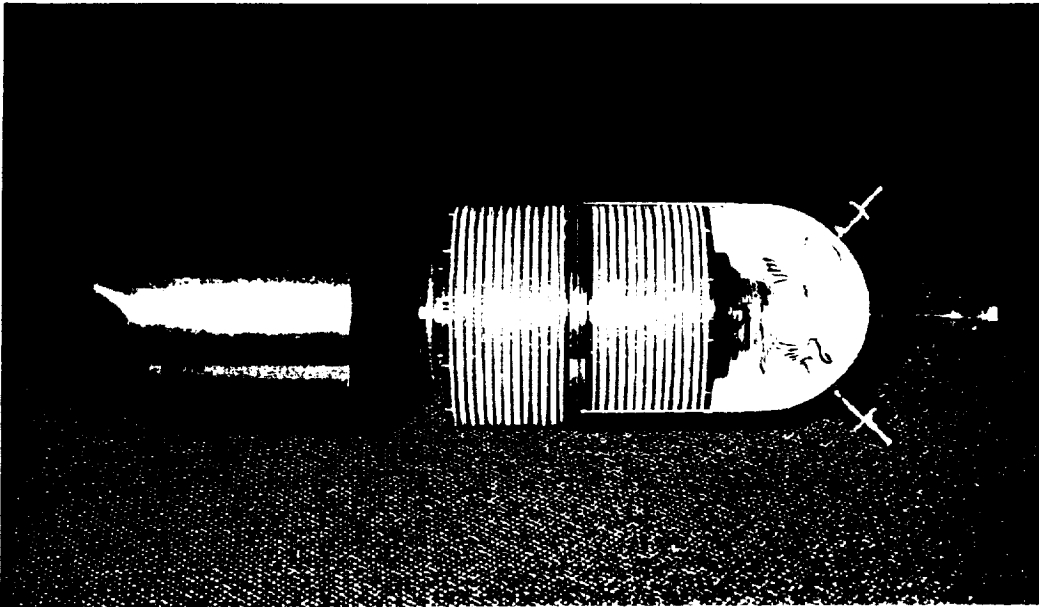
The packs provided early data on the operation of HST Ni-H₂ cells cycled according to a Voltage versus Temperature (VT) curve already in place for use on the HST with Ni-Cd batteries. The test bed uses programmable power supplies and load banks with digital system control and data collection while solar array decay, seasonal sun intensity, off nominal roll and other parameters are variable. These cells were used for parametric testing on Ni-H₂ cells of HST design. This test will continue HST LEO cycling when not performing system evaluation tests.

HST Ni-H₂ Three, 4-Cell Packs



Eagle Picher RNH-90-3

Developed for the Hubble Space Telescope



Testing of RNH-90-3 Cells

- HST Ni-H2 Three, 4-Cell Packs
- HST Ni-H2 Six Battery Test
- HST "Flight Spare" Battery Test
- Ni-H2 Two, 2-Cell Packs
- Ni-H2 Six, 4-Cell Packs at 22 & 33% DOD

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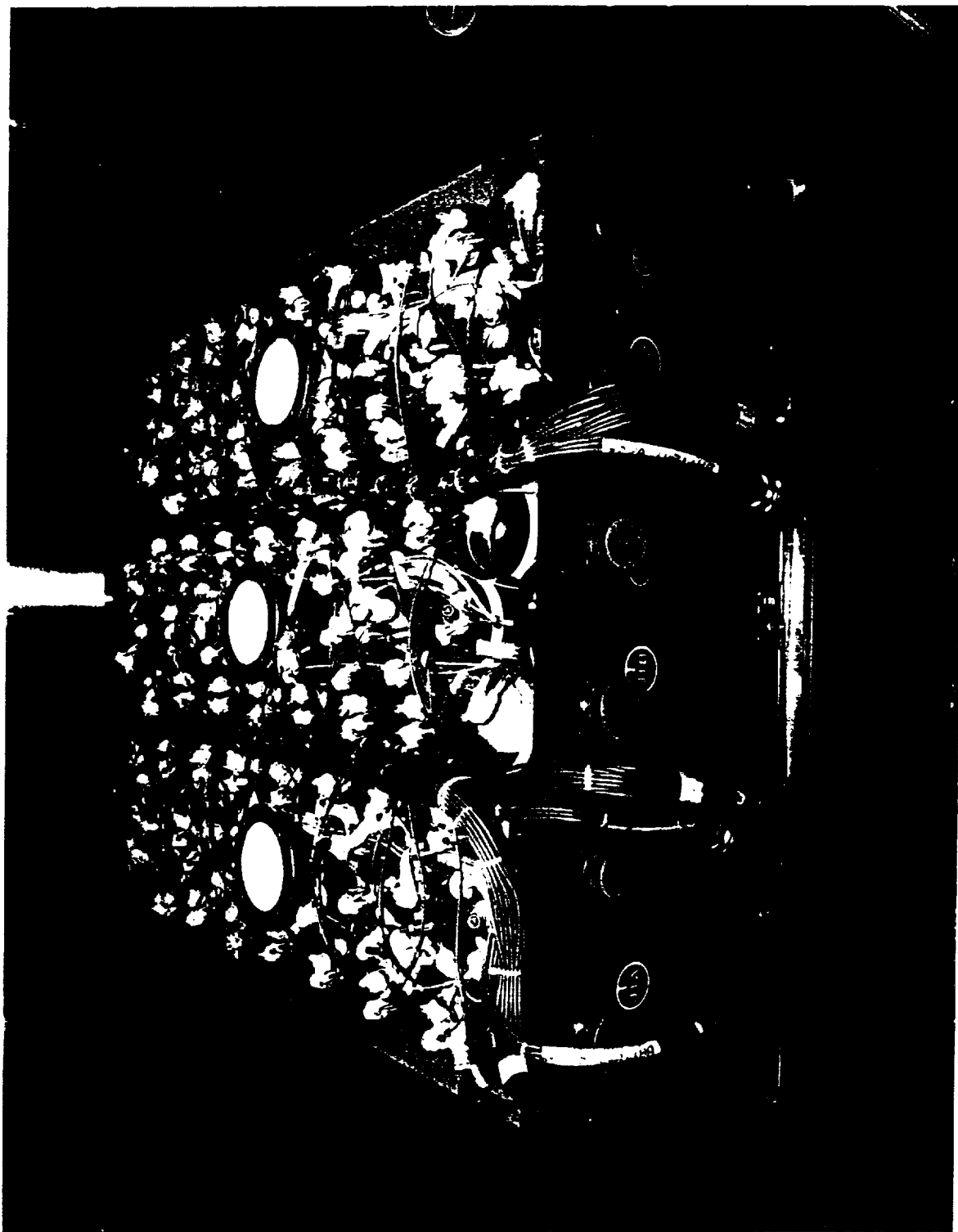
HST Ni-H₂ Six Battery Test

- 88 ampere-hour cells developed by Eagle Picher Inc. for the HST project. RNH-90-3
- 22 cells/battery, 6 batteries in parallel (3 batteries from the TM1 lot and 3 batteries from the TM2 lot)
- DODs range from 6 to 9% of the battery nameplate capacity.
- Battery cycling capacities vary from 75 to 80 Ah.
- 13,200 cycles (29 months) as of 10/21/91
- 11 month lead time on the HST mission

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HST Ni-H₂ Six Battery System Simulation - A full scale Hubble Space Telescope (HST) Ni-H₂ six battery electrical power system simulation began in May of 1989. This test utilized Test Module 1 (TM1) and Test Module 2 (TM2) cells (six 23 cell batteries) in a flight configuration with full instrumentation. Solar panel assemblies (SPAs) were simulated by power supplies, the electrical load by programmable load banks and the actual DF-224 by a system control computer. The test system has safety and protection measures built in to prevent catastrophic failure (fuses, overtemperature shutdowns, power timeout circuits, uninterruptible power supply and auto dialer). This test provides life cycle data on the HST Ni-H₂ modules in a low earth orbit (LEO) power system; these modules are operating at the current HST Charge Current Control (CCC) levels in a 0°C environment.

To date, over 13,200 cycles have been completed on the system with nominal performance noted. Optimum operating parameters previously indicated were confirmed by the system simulation. The simulation will continue to operate for an undetermined period of time in support of the HST.



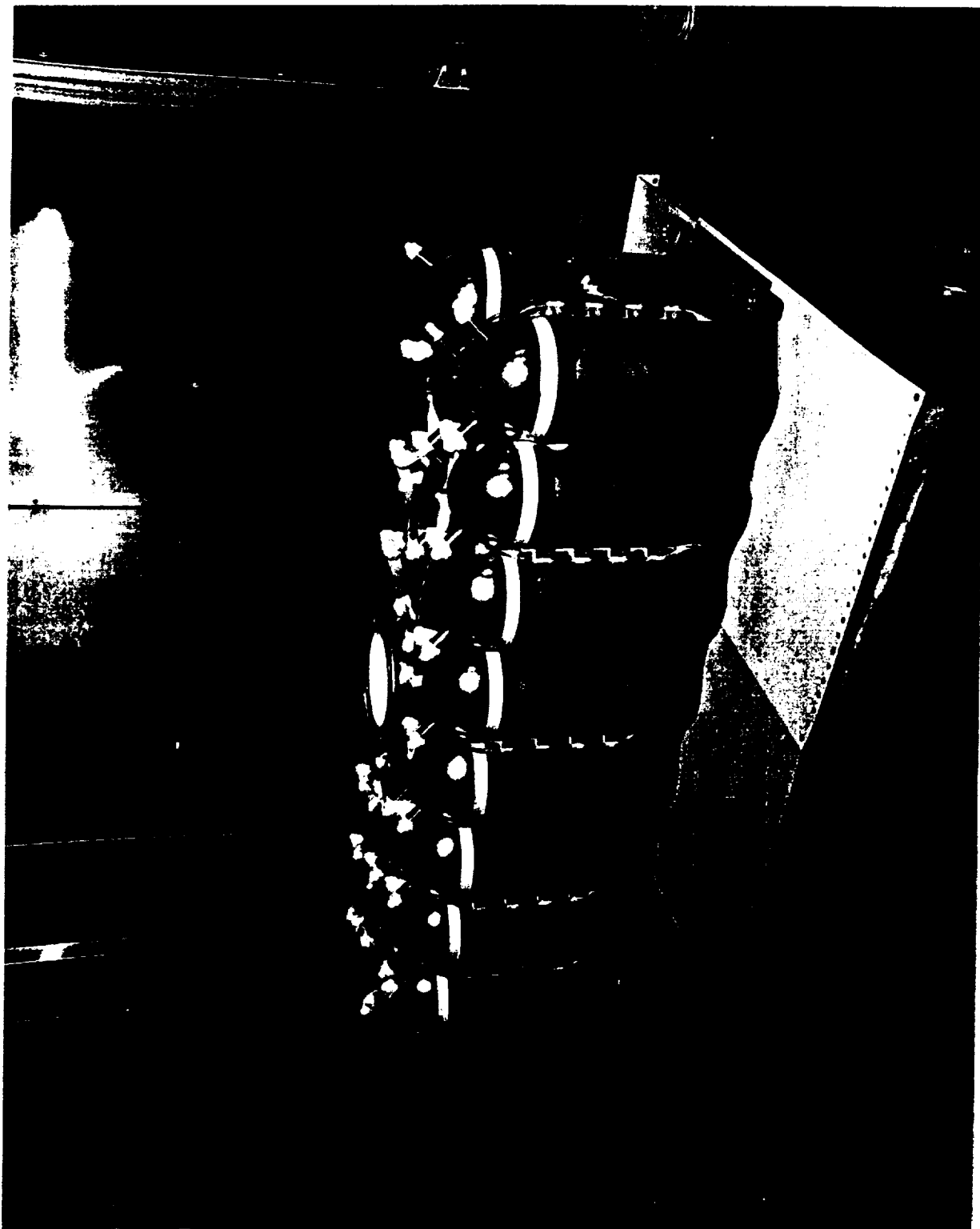
HST Ni-H₂ Three Battery Module

HST Ni-H2 "Flight Spare" Battery

- 88 ampere-hour cells developed by Eagle Picher Inc. for the HST project. RNH-90-3
- 22 cells from the Flight Spare Lot of cells
- DOD ranges from 6 to 9% of the battery nameplate capacity.
- Battery cycling capacities vary from 70 to 78 Ah.
- 12,800 cycles (28 months) as of 10/21/91
- 10 month lead time on the HST mission

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HST Ni-H2 "Flight Spare" Battery - One twenty two cell battery made up of Hubble Space Telescope (HST) cells (Eagle-Picher RNH-90-3) left over from the Flight Spare Module (FSM) lot (with full instrumentation, in flight configuration) was delivered to MSFC in June 1989 and entered a test program similar to the six battery system simulation. The test bed is automated with digital data acquisition, programmable loads and programmable power supplies and has safety features equivalent to the 6 Battery System Simulation. This is a battery life test simulating actual HST operation. The test has completed over 12,800 life cycles and will continue to support the HST and add to the low earth orbit (LEO) database.



HST Ni-H₂ "Flight Spare" Battery

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Ni-H₂ Two, 2 Cell Packs

- 88 ampere-hour cells developed by Eagle Picher Inc. for the HST project. RNH-90-3
- Previously used in the HST 4 Cell Pack Testing.
- 1 pack with 26% KOH / 1 pack at 31% KOH
- Compare performance of the KOH concentrations at high DODs (20-50%) in a LEO cycling profile
- 24 months of testing at the higher DODs

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Ni-H₂ Two, 2-Cell Packs - Four test cells from the Hubble Space Telescope (HST) engineering lot of cells (Eagle-Picher RNH-90-3) are divided into two packs of two cells dependent upon their electrolyte concentration (2 cells with 26% KOH, Pack #1; and 2 cells with 31% KOH, Pack #2). On line since 1988, this test was set up to research the behavior of Ni-H₂ cells of HST design, having differing electrolyte concentrations, when operated at high depths of discharge (20% - 50%) in a low earth orbit cycling program. This test utilizes cells which were previously used in the HST three, 4-cell pack testing program. These cells are currently cycling according to a parametric test matrix which will be completed in 1992.

EAGLE PICHER RNH-90-3 CELLS CYCLING AT 22% & 33% DODs

- 88 ampere-hour cells developed by Eagle Picher Inc. for the HST project.
- Four 4-cell packs cycling at 22% DOD
Two 4-cell packs cycling at 33% DOD
- Gather data to determine best charge control method to use for Ni-H₂ cells at moderate DODs.
- Study the effect of reconditioning on Ni-H₂ cells.
- Demonstrate the ability of the HST design to provide extended life cycle at DODs required by AXAF, Space Station, etc.

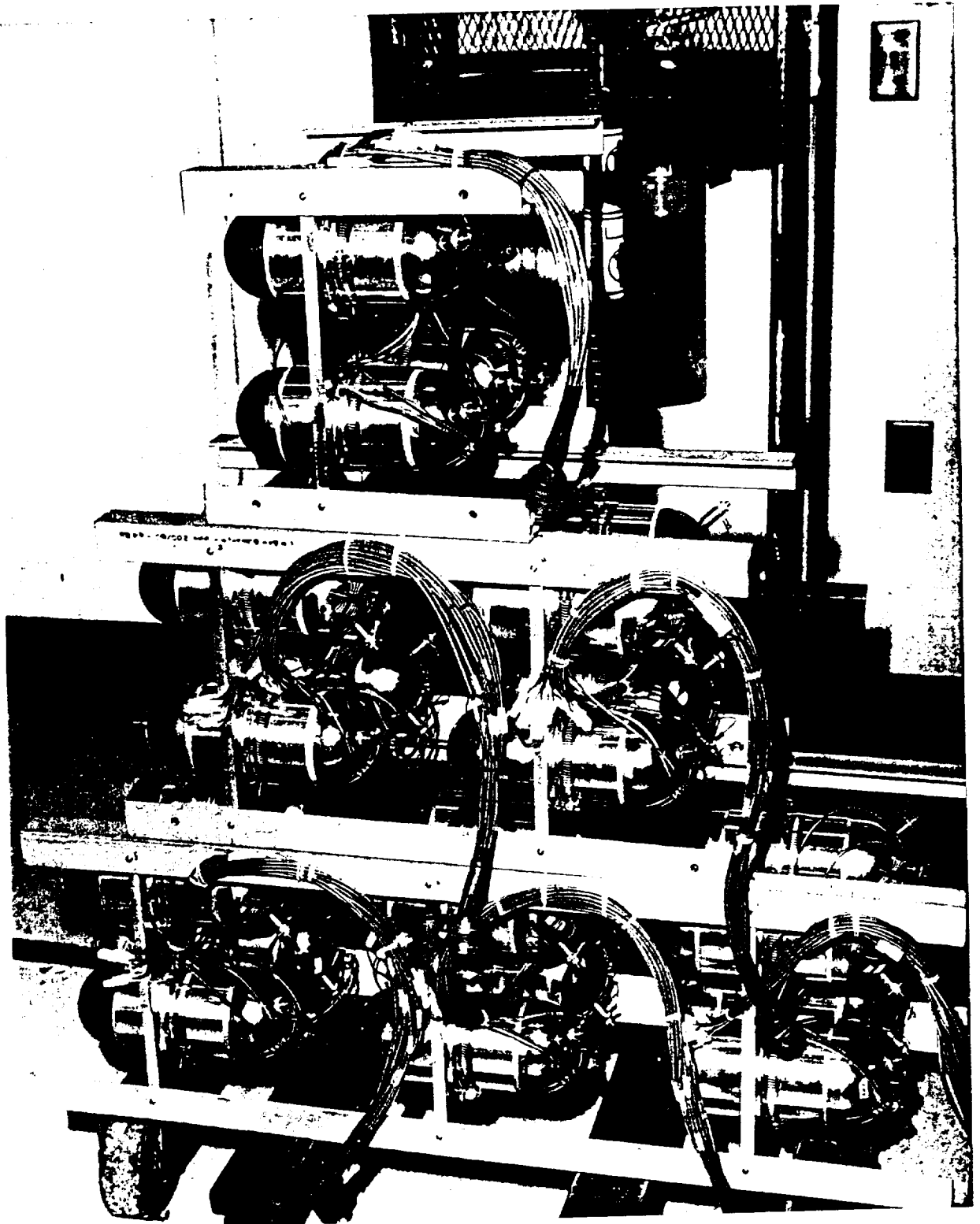
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Six, Ni-H₂ 4-Cell Packs - This test utilizes 24 Eagle-Picher RNH-90-3 Ni-H₂ cells from the Hubble Space Telescope (HST) program. The cells are low earth orbit (LEO) cycling on a 61/35 orbit. On line since May of 1991, the purpose of this test is to evaluate the performance and operating characteristics of the HST cell at moderate depths of discharge (DOD's) and investigate the long term effects of periodic reconditioning.

The cells are divided into six packs of four cells each based on their manufacturing lot. Two of the packs are cycling at 22% DOD and will be used to study the effects of reconditioning. These two packs charge until a set recharge ratio (RR) is achieved then, step to a trickle charge level. One of these packs will be reconditioned periodically while the other is not. The electrical performance of the two packs as well as the electrochemical effects of the reconditioning through destructive physical analysis (DPA) will be monitored.

Four packs are dedicated to studying the performance of the cells at moderate DOD's. Two of the packs are LEO cycling at 22% DOD while the other two are cycling at 33% DOD. One pack at 22% and one pack at 33% are charging to a recharge ratio with a voltage versus temperature (VT) curve to limit overvoltage on the cell. The packs step to trickle after achieving the RR. The remaining packs (1 at 22% and 1 at 33%) are also charging to a RR; but, the charge cutback to half the original charge current is controlled by sensing the beginning of overcharge. The current then steps to a trickle level after reaching the RR.

Six, Ni-H₂ 4-Cell Packs



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Testing of Eagle Picher RNH-90-3 at MSFC Summary

<u>TEST</u>	<u># of Cells</u>	<u>Cycling DOD</u>	<u>Project(s)</u>	<u>Months of testing</u>
HST NI-H2 4-Cell Packs	12	6 - 9%	HST	34, 32, 30
HST NI-H2 Six Battery Test	132	6 - 9%	HST	29
HST "Flight Spare" Battery Test	22	6 - 9%	HST	28
NI-H2 2-Cell Packs	4	20 - 50%	_____	24
NI-H2 4-Cell Packs at 22 & 33% DOD	24	22 & 33%	AXAF SS Freedom	4